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14. ABSTRACT
The problem of distributed estimation/tracking/localization in a bandwidth/power constrained wireless sensor network is studied.
Significant progress has been made on several fronts:
i) Introduced the concept of estimation diversity in the context of distributed sensing and established its tradeoff with energy efficiency.

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Report Title

Mathematical Analysis of Signal Processing Capabilities of Wireless Networks

ABSTRACT

The problem of distributed estimation/tracking/localization in a bandwidth/power constrained wireless sensor network is studied. Significant progress has been made on several fronts:
i) Introduced the concept of estimation diversity in the context of distributed sensing and established its tradeoff with energy efficiency.

ii) Proposed efficient convex optimization based relaxation algorithms for target localizations using a sensor network. The performance of these algorithms can closely approximate the Cramer-Rao lower bounds.

iii) Optimal rate and power allocation is obtained for the multiterminal source-channel communication from an information theoretic viewpoint. Distributed spectrum management methods for interference-limited multiuser communication systems are introduced and analyzed.

iv) It has been shown that for distributed optimization in an energy-constrained network, digital communication scheme is far more energy efficient than analog communication scheme. The gap in communication energy consumption can be exponential.

v) The tracking and localization performance of sensor networks has been analyzed under a given resource efficiency.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

(1) “Distributed Sensor Network Localization Using SOCP Relaxation”
- Authors: Srirangarajan, S., Tewfik, A. and Luo, Z.-Q.
- Accepted for publication in IEEE Transactions on Wireless Communications, 2008.
- Abstract: The goal of the sensor network localization problem is to determine positions of all the sensor nodes in a network given certain pairwise noisy distance measurements and inaccurate anchor node positions. A two-step distributed localization approach based on second-order cone programming (SOCP) relaxation is presented. In the first step, the sensor nodes determine their positions based on local information and in the second step, the anchor nodes refine their positions using information from the neighboring nodes. Our numerical study shows that the sensor and anchor positions cannot be estimated in a single step; the sensors must be estimated first for the results to converge. The second step enables anchors which are in the convex hull of their neighbors to refine their positions. Extensive simulation results with inaccurate anchor positions and noisy distance measurements are presented. These illustrate the robustness of the algorithm and the performance gains achievable in terms of problem size reduction, computational efficiency and localization accuracy.

(2) “Distributed Beamforming for Relay Networks based on Second Order Statistics of the Channel State Information”
- Authors: Nassab, V.M., Shahbazpanahi, S., Grami, A. and Luo, Z.-Q.
- IEEE Transactions on Signal Processing, Vol. 56, No 9, pp. 4306-4316, September 2008.
- Abstract: In this paper, the problem of distributed beamforming is considered for a wireless network which consists of a transmitter, a receiver, and r relay nodes. For such a network, assuming that the second-order statistics of the channel coefficients are available, we study two different beamforming design approaches. As the first approach, we design the beamformer through minimization of the total transmit power subject to the receiver quality of service constraint. We show that this approach yields a closed-form solution. In the second approach, the beamforming weights are obtained through maximizing the receiver signal-to-noise ratio (SNR) subject to two different types of power constraints, namely the total transmit power constraint and individual relay power constraints. We show that the total power constraint leads to a closed-form solution while the individual relay power constraints result in a quadratic programming optimization problem. The later optimization problem does not have a closed-form solution. However, it is shown that using semidefinite relaxation, this problem can be turned into a convex feasibility semidefinite programming (SDP), and therefore, can be efficiently solved using interior point methods. Furthermore, we develop a simplified, thus suboptimal, technique which is computationally more efficient than the SDP approach. In fact, the simplified algorithm provides the beamforming weight vector in a closed form. Our numerical examples show that as the uncertainty in the channel state information is increased, satisfying the quality of service constraint becomes harder, i.e., it takes more power to satisfy these constraints. Also our simulation results show that when compared to the SDPbased method, our simplified technique suffers a 2-dB loss in SNR for low to moderate values of transmit power.

(3) “Multiterminal Source-Channel Communication Over an Orthogonal Multiple-Access Channel”
- Authors: Xiao, J.-J. and Luo, Z.-Q.
- IEEE Transactions on Information Theory, Vol. 53, No. 9, pp. 3255-3264, September 2007.
- Abstract: We consider the problem of multiterminal sourcechannel communication where a number of distributed and possibly correlated sources are transmitted through an orthogonal multiple access Channel to a common destination. We provide a characterization of the optimal tradeoff between the transmission cost \Gamma and the distortion vector D as measured against individual sources. Our approach consists of two steps: 1) a multipleletter characterization of the rate-distortion region of the multiterminal source coding and 2) a sourcechannel separation theorem ensuring that all achievable pairs of (\Gamma;D) can be obtained by combining the rate-distortion region and the orthogonal multiple access channel capacity region. As a corollary, we determine the optimal power and distortion tradeoff in a quadratic Gaussian sensor network under orthogonal multiple access, and show that separate source and channel coding strictly outperforms the uncoded (amplify-forward) transmission, and is in fact optimal in this case. This result is in sharp contrast to the case of nonorthogonal multiple access for which separate source and channel coding is not only suboptimal but also strictly inferior to uncoded transmission.

(4) “Linear Coherent Decentralized Estimation”
- Authors: Xiao, J.-J., Cui, S., Luo, Z.-Q., and Goldsmith, A.J.
- IEEE Transactions on Signal Processing, Vol. 56, No. 2, pp. 757-770, February 2008.
- Abstract: We consider the distributed estimation of an unknown vector signal in a resource constrained sensor network with a fusion center. Due to power and bandwidth limitations, each sensor compresses its data in order to minimize the amount of information that needs to be communicated to the fusion center. In this context, we study the linear decentralized estimation of the source vector, where each sensor linearly encodes its observations and the fusion center also applies a linear mapping to estimate the unknown vector signal based on the received messages. We adopt the mean squared error (MSE) as the performance criterion. When the channels between sensors and the fusion center are orthogonal, it has been shown previously that the complexity of designing the optimal encoding matrices is NP-hard in general. In this paper,we study the optimal linear decentralized estimation when the multiple access channel (MAC) is coherent. For the case when the source and observations are scalars, we derive the optimal power scheduling via convex optimization and show that it admits a simple distributed implementation. Simulations show that the proposed power scheduling improves the MSE performance by a large margin when compared to the uniform power scheduling. We also show that under a finite network power budget, the asymptotic MSE performance

(when the total number of sensors is large) critically depends on the multiple access scheme. For the case when the source and observations are vectors,
we study the optimal linear decentralized estimation under both bandwidth and power constraints. We show that when the MAC between sensors and the fusion center is noiseless, the resulting problem has a closed-form solution (which is in sharp contrast to the orthogonal MAC case), while in the noisy MAC case, the problem can be efficiently solved by semidefinite programming (SDP).

(5) “Estimation Diversity and Energy Efficiency in Distributed Sensing”
- Authors: Cui, S., Xiao, J.-J., Goldsmith, A.J., Luo, Z.-Q., and Poor, H.V.
- IEEE Transactions on Signal Processing, Vol.55, No. 9, pp. 4683-4695, 2007.
- Abstract: Distributed estimation based on measurements from multiple wireless sensors is investigated. It is assumed that a group of sensors observe the same quantity in independent additive observation noises with possibly different variances. The observations are transmitted using amplify-and-forward (analog) transmissions over nonideal fading wireless channels from the sensors to a fusion center, where they are combined to generate an estimate of the observed quantity. Assuming that the best linear unbiased estimator (BLUE) is used by the fusion center, the equal-power transmission strategy is first discussed, where the system performance is analyzed by introducing the concept of estimation outage and estimation diversity, and it is shown that there is an achievable diversity gain on the order of the number of sensors. The optimal power allocation strategies are then considered for two cases: minimum distortion under power constraints; and minimum power under distortion constraints. In the first case, it is shown that by turning off bad sensors, i.e., sensors with bad channels and bad observation quality, adaptive power gain can be achieved without sacrificing diversity gain. Here, the adaptive power gain is similar to the array gain achieved in multiple-input single-output (MISO) multiantenna systems when channel conditions are known to the transmitter. In the second case, the sum power is minimized under zero-outage estimation distortion constraint, and some related energy efficiency issues in sensor networks are discussed.

(6) “Distributed Estimation Using Reduced Dimensionality Sensor Observations”
- Authors: Schizas, I.D., Giannakis, G.B. and Luo, Z.-Q.
- IEEE Transactions on Signal Processing, Vol. 55, No. 8, pp. 4284-4299, August 2007.
- Abstract: We deal with linear estimation of random signals based on reduced-dimensionality observations collected at distributed sensors and communicated to a fusion center through wireless links. Dimensionality reduction compresses sensor data to meet low-power and bandwidth constraints, while linearity in compression and estimation are well motivated by the limited computing capabilities wireless sensor networks are envisioned to operate with. We cast this intertwined compression-estimation problem in a canonical correlation analysis framework, and derive closed-form along with coordinate descent estimators which guarantee convergence at least to a stationary point. Performance analysis and corroborating simulations demonstrate the merits of the novel distributed estimators relative to existing alternatives.

Number of Papers published in peer-reviewed journals: 6.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

(1) ”Distributed Optimization in an Energy-Constrained Network”
- Authors: Razavi, A. and Luo, Z.-Q.
- Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing, Vol. 3, pp.189-pp.192, April 2007.
- Abstract: We consider a distributed optimization problem whereby two nodes S1, S2 wish to jointly minimize a common convex quadratic cost function f(x1; x2), subject to separate local constraints on x1 and x2, respectively. Suppose that node S1 has control of variable x1 only and node S2 has control of variable x2 only. The two nodes locally update their respective variables and periodically exchange their values over a noisy channel. Previous studies of this problem have mainly focused on the convergence issue and the analysis of convergence rate. In this work, we focus on the communication energy and study its impact on convergence. In particular, we consider a class of distributed stochastic gradient type algorithms implemented using certain linear analog messaging schemes. We study the minimum amount of communication energy required for the two nodes to compute an \epsilon-minimizer of f(x1; x2) in the mean square sense. Our analysis shows that the communication energy must grow at least at the rate of -\Omega(\epsilon^(-1)). We also derive specific designs which attain this minimum energy bound, and provide simulation
results that confirm our theoretical analysis. Extension to the multiple node case is described.

(2) “Dynamic Spectrum Management: When is FDMA Sum-Rate Optimal?”
- Authors: Hayashi, S. and Luo, Z.-Q.
- roceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing, Vol. 3, pp. pp.609-pp.612, April 2007.
- Abstract: Consider a multiuser communication system in a frequency selective environment whereby users share a common spectrum and can interfere with each other. Assuming Gaussian signaling and treating interference as noise, we study optimal spectrum sharing strategies for the maximization of weighted sum-rate. In this work,we show that, if the normalized crosstalk gains are larger than a given threshold (roughly equal to 1/2), then the optimal spectrum sharing strategy is Frequency Division Multiple Access (FDMA). We also propose several simple distributed spectrum allocation algorithms that can approximately maximize weighted sum-rates. Numerical simulation of DSL applications shows that these algorithms are efficient and can achieve substantially larger weighted sumrates than those obtained by the existing Iterative Water-filling algorithm.

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 2

(d) Manuscripts

(1) ”Distributed estimation and collaborative sensing in wireless sensor networks”
- Authors: Xiao, J.-J., Cui, S., and Luo, Z.-Q.
- To appear in Handbook on Array Processing and Sensor Networks (Haykin, Simon and Liu, K. J. Ray, eds.), Wiley Publishers, 2008.
- Abstract: One of the challenges in a wireless sensor network (and other mobile networks) is the stringent energy constraint. In this work we investigated the energy-efficient decentralized estimation in a wireless sensor network with a fusion center. We discussed both the analog and digital approaches, carried out the corresponding algorithm design, and studied the optimal resource scheduling. In addition, we considered the complexity of the signal processing design, and also from a communication perspective, studied how the multiple access scheme of the sensor nodes to the fusion center affects decentralized estimation performance.

(2) “A Generalized Iterative Water-filling Algorithm for Distributed Power Control in the Presence of a Jammer”
- Authors: Gohary, R., Huang, Y., Luo, Z.-Q. and Pang, J.-S.
- Manuscript, Department of Electrical and Computer Engineering, University of Minnesota. To appear in IEEE Transaction of Signal Processing 2009.
- Abstract: Consider a scenario in which K users and a jammer share a common spectrum of N orthogonal tones. Both the users and the jammer have limited power budgets. The goal of each user is to allocate its power across the N tones in such a way that maximizes the total sum rate that he/she can achieve, while treating the interference of other users and the jammer’s signal as additive Gaussian noise. The jammer, on the other hand, wishes to allocate its power in such a way that minimizes the utility of the whole system; that being the total sum of the rates communicated over the network. For this non-cooperative game, we propose a generalized version of the existing iterative water-filling algorithm whereby the users and the jammer update their power allocations in a greedy manner. We study the existence of a Nash equilibrium of this non-cooperative game as well as conditions under which the generalized iterative water-filling algorithm converges to a Nash equilibrium of the game. The conditions that we derive in this paper depend only on the system parameters, and hence can be checked a priori. Simulations show that when the convergence conditions are violated, the presence of a jammer can cause the, otherwise convergent,
iterative water-filling algorithm to oscillate.

(3) “Distributed Optimization in an Energy-constrained network using a Digital Communication Scheme”
- Authors: Razavi, Alireza, Luo, Z.-Q. and Modiano, E.
- Manuscript, Department of Electrical and Computer Engineering, University of Minnesota. Submitted for publication, 2008.
- Abstract: We consider a distributed optimization problem where n nodes, S_l, l \in {1,...,n}, wish to minimize a common strongly convex function f(x), x = [x_1,...,x_n]^T , and suppose that node S_l only has control of variable x_l. The nodes locally update their respective variables and periodically exchange their values over noisy channels. Previous studies of this problem have mainly focused on the convergence issue and the analysis of convergence rate. In this work, we focus on the communication energy and study its impact on convergence. In particular, we study the minimum amount of communication energy required for nodes to obtain an \epsilon-minimizer of f(x) in the mean square sense. In an earlier work, we considered analog communication schemes and proved that the ommunication energy must grow at the rate of \Omega-(\epsilon^(-1)) to obtain an \epsilon-minimizer of a convex quadratic function. In this paper, we consider digital communication schemes and propose a distributed algorithm which only requires communication energy of O((log\epsilon ^(-1))^3) to obtain an \epsilon-minimizer of f(x). Furthermore, the algorithm provided herein converges linearly. Thus, it requires less energy for local computation at each node to obtain an \epsilon-minimizer.

(4) “Efficient Convex Relaxation Methods for Robust Target Localization by a Sensor Network Using Time Differences of Arrivals”
- Authors: Yang, K., Wang, G., and Luo, Z.-Q.
- Submitted to IEEE Transactions on Signal Processing, April 2008. accepted for publication.
- Abstract: We consider the problem of target localization by a network of passive sensors. When an unknown target emits an acoustic or a radio signal, its position can be localized with multiple sensors using the time difference of arrival (TDOA) information. In this paper, we consider the maximum likelihood formulation of this target localization problem and provide efficient convex relaxations for this nonconvex optimization problem. We also propose a formulation for robust target localization in the presence of sensor location errors. Two Cramer-Rao bounds are derived corresponding to situations with and without sensor node location errors. Simulation results confirm the efficiency and superior performance of the convex relaxation approach as compared to the existing least squares based approach when large sensor node location errors are present.

Number of Manuscripts: 4.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
Mikalai Kisialiou	1.00
Yao Huang	0.50
Alireza Razavi	0.50
Jinjun Xiao	0.50
FTE Equivalent:	**2.50**
Total Number:	**4**

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Zhi-Quan Luo	0.08	No
FTE Equivalent:	**0.08**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
Heon Hwa Cheng	0.00
FTE Equivalent:	**0.00**
Total Number:	**1**

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	1.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:.....	1.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:.....	1.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):	1.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:	0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Jinjun Xiao
Mikalai Kisialiou
Total Number: 2

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

ARO Final Report
January 2009

Mathematical Analysis of Signal Processing Capabilities of Wireless Networks

Zhi-Quan Luo

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University of Minnesota
Minneapolis, MN 55455

Contents

1 List of illustrations

2 Statement of the problem studied

A wide range of communication problems in the context of resource constrained wireless sensor networks have been studied. We focus on the more power/bandwidth efficient distributed methods on the problems such as estimation, tracking and localization. Dynamic spectrum management in an interference-limited multiuser communication system is also studied.

3 Summary of the most important results

The problem of distributed estimation/tracking/localization in a bandwidth/power constrained wireless sensor network is studied. Significant progress has been made on several fronts:

3.1 Distributed optimization in an energy constrained sensor network

We introduced the concept of estimation diversity in the context of distributed sensing and established its tradeoff with energy efficiency and have shown that for distributed optimization in an energy-constrained network, digital communication scheme is far more energy efficient than analog communication scheme. The gap in communication energy consumption can be exponential.We consider a distributed optimization problem where n nodes, S_l, $l \in \{1, \ldots, n\}$, jointly minimize a common strongly convex function $f(\mathbf{x})$, $\mathbf{x} = [x_1, \ldots, x_n]^T$, and suppose that node S_l only has control of variable x_l. The nodes locally update their respective variables and periodically exchange their values over noisy channels. Previous studies of this problem have mainly focused on the convergence issue and the analysis of

convergence rate. In this work, we focus on the communication energy and study its impact on convergence. In particular, we study the minimum amount of communication energy required for nodes to obtain an ϵ-minimizer of $f(\mathbf{x})$ in the mean square sense. We consider both analog and digital communication schemes. For the former, we study a class of distributed stochastic gradient type algorithms implemented using certain linear analog messaging schemes. Our analysis shows that the communication energy to obtain an ϵ-minimizer of $f(\mathbf{x})$ must grow at least at the rate of ϵ^{-1}. We derive a specific design which attains this minimum energy bound within a factor of at most 3 to the minimum communication energy for convex quadratic functions. For digital communication scheme, we introduce a distributed algorithm based on gradient projection method which requires $\mathcal{O}(\log \epsilon^{-1})^3$ communication energy. Furthermore, the algorithm provided for the digital communication scheme converges linearly compared with the algorithm for the analog communication scheme which has a sub-linear convergence rate (Figure 1). Thus, asymptotically digital communication schemes are far more energy efficient than analog communication schemes for distributed optimization. This does not mean that the digital framework outperforms the analog framework in terms of energy for any value of mean squared error. For example, in our simulation, the analog framework requires less energy to obtain an ϵ-minimizer of $f(\mathbf{x})$ compared with digital framework for $\epsilon \geq 10^{-6}$ (Figure 2). For value $\epsilon \leq 10^{-6}$, the digital framework consumes less energy than the analog framework.

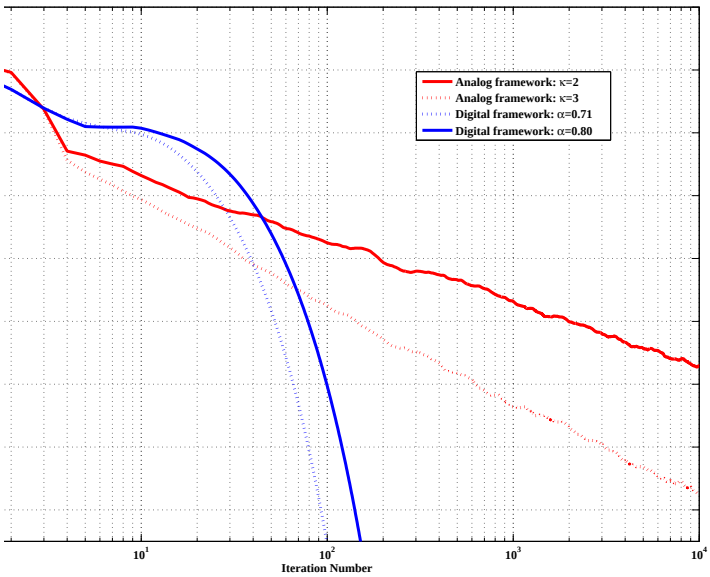

Figure 1. Mean squared error versus iteration number

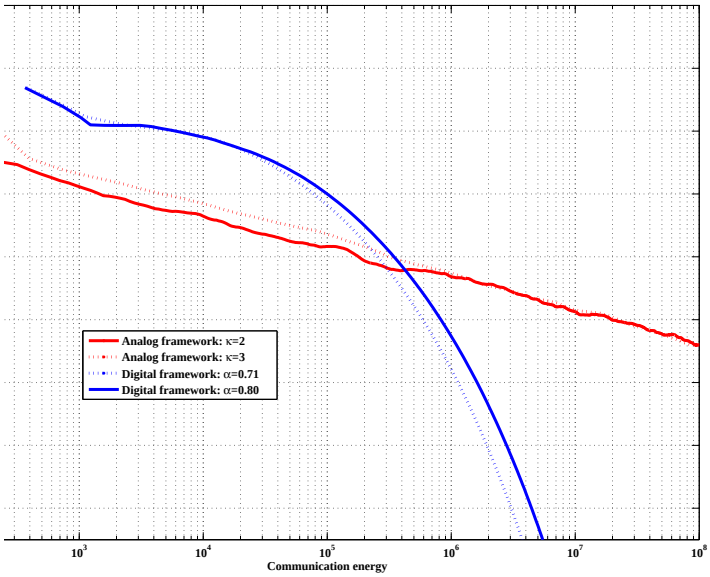

Figure 2. Mean squared error versus communication energy

3.2 Robust target localization in a sensor network

We considered the maximum likelihood formulation of this target localization problem and proposed efficient convex optimization based relaxation algorithms for target localizations in a sensor network using TDOA. The Semidefinite Programming (SDP) relaxations for both the non-robust and robust formulations are given. The performance of these algorithms can closely approximate the Cramer-Rao lower bounds (CRB). From Figure 3, we can see that the proposed robust localization method achieves the corresponding CRB in both the near field and the far field cases, and that the more TDOA measurement samples and node location observations, the better the performance of the target location estimation. In order to compare the performance of the SDP robust approach with the weighted least square method, we plotted the RMSE of the proposed robust target localization method (abbreviated as 'SDP robust') and the RMSE of the weighted least square method (abbreviated as 'weighted LS') in Figure 4 for the near and far field cases, respectively. From the figure, we see that our proposed robust approach closely follows the CRB, and clearly outperforms the 'weighted LS' method especially when the measurement noise and the node location observation errors become large.

3.3 Information theoretic analysis: rate and power allocation

Optimal rate and power allocation is obtained for the multiterminal source-channel communication from an information theoretic viewpoint. We provide a characterization of the optimal tradeoff between the transmission cost Γ and the distortion vector D as measured against

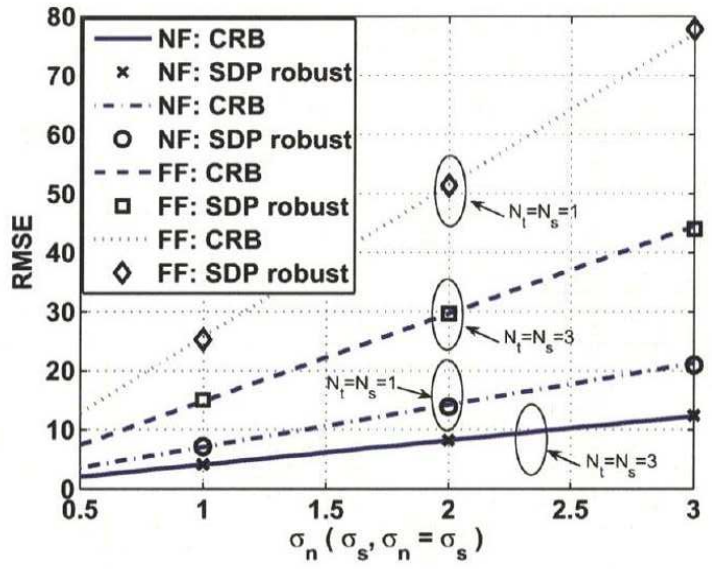

Figure 3. RMSE of target location estimation versus the measurement noise and node location error in the near and far field cases, where 'NF' stands for 'near field case', and 'FF' stands for 'far field case'.

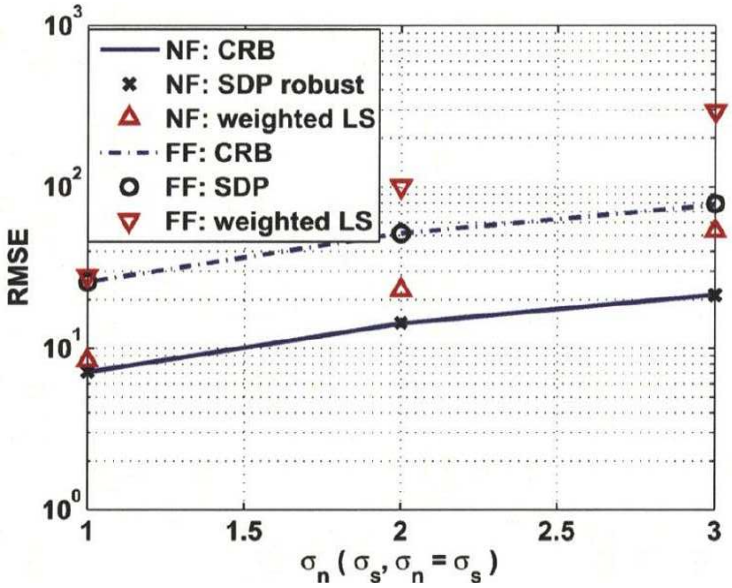

Figure 4. RMSE of 'SOP robust' and 'weighted LS' in the near and far field cases, where 'NF' stands for 'near field case', and 'FF' stands for 'far field case'.

individual sources. Our approach consists of two steps: 1) a multiple-letter characterization of the rate-distortion region of the multiterminal source coding and 2) a sourcechannel separation theorem ensuring that all achievable pairs of (Γ, D) can be obtained by combining the rate-distortion region and the orthogonal multiple access channel capacity region. As a corollary, we determine the optimal power and distortion tradeoff in a quadratic Gaussian

sensor network under orthogonal multiple access, and show that separate source and channel coding strictly outperforms the uncoded (amplify-forward) transmission, and is in fact optimal in this case. This result is in sharp contrast to the case of nonorthogonal multiple access for which separate source and channel coding is not only suboptimal but also strictly inferior to uncoded transmission.

We have also analyzed the tracking and localization performance of sensor networks under a given resource efficiency. Studied the impact of communication noise in the design of optimization algorithms for wireless sensor network and analyzed the rate-distortion region for a Gaussian wireless sensor networks.

3.4 Dynamic spectrum management: complexity and duality

We have studied dynamic spectrum management and designed algorithms in an interference-limited multiuser communication system. Achieved breakthrough on the asymptotic strong duality in this context. We have used a convexity result of Lyapunov to estimate the size of duality gap for the discretized spectrum management problem and shown that the duality gap vanishes asymptotically at the rate $\mathcal{O}(1/\sqrt{N})$, where N is the size of the uniform discretization of the shared spectrum. If the channels are frequency flat, the duality gap estimate improves to $\mathcal{O}(1/N)$. Moreover, when restricted to the FDMA spectrum sharing strategies, we show that the Lagrangian dual relaxation, combined with a linear programming scheme, can generate an ϵ-optimal solution for the continuous formulation of the spectrum management problem in polynomial time for any $\epsilon > 0$.

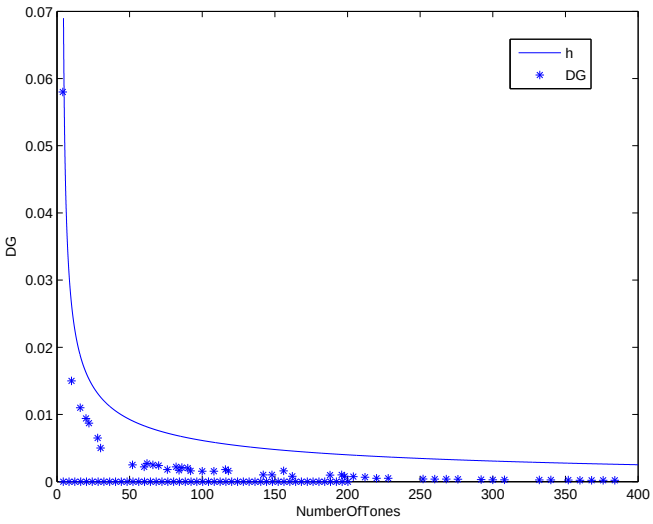

Figure 5. Duality gap v.s. N

4 Bibliography

(I) **Manuscripts submitted, but not published**

(1) "Distributed estimation and collaborative sensing in wireless sensor networks"

- *Authors:* Xiao, J.-J., Cui, S., and Luo, Z.-Q.
- To appear in Handbook on Array Processing and Sensor Networks (Haykin, Simon and Liu, K. J. Ray, eds.), Wiley Publishers, 2008.

(2) "Efficient Soft Demodulation of MIMO QPSK via Semidefinite Relaxation"

- *Authors:* Nekuii, M., Kisialiou, M., Davidson, T. N. and Luo, Z.-Q.
- Submitted to IEEE Transactions on Signal Processing, April 2008.

(3) "Efficient Convex Relaxation Methods for Robust Target Localization by a Sensor Network Using Time Differences of Arrivals"

- *Authors:* Yang, K., Wang, G., and Luo, Z.-Q.
- Accepted for publication in IEEE Transactions on Signal Processing, December 2008.

(II) **Papers published in peer-reviewed journals**

(1) "Design of Phase Codes for Radar Performance Optimization with a Similarity Constraint"

- *Authors:* De Maio, A., De Nicola, S., Huang, Y., Luo, Z.-Q. and Zhang, S.
- Accepted for publication in IEEE Transactions on Signal Processing.

(2) "Spectrum Management for Interference-limited Multiuser Communication Systems"

- *Authors:* Hayashi, S. and Luo, Z.-Q.
- Accepted for publication in IEEE Transactions on Information Theory

(3) "Distributed Sensor Network Localization Using SOCP Relaxation"

- *Authors:* Srirangarajan, S., Tewfik, A. and Luo, Z.-Q.
- Accepted for publication in IEEE Transactions on Wireless Communications, 2008.

(4) "Distributed Beam-forming for Relay Networks based on Second Order Statistics of the Channel State Information"

- *Authors:* Nassab, V.M., Shahbazpanahi, S., Grami, A. and Luo, Z.-Q.
- IEEE Transactions on Signal Processing, Vol. 56, No. 9, pp. 4306-4316, September 2008.

(5) "Multiterminal Source-Channel Communication Over an Orthogonal Multiple-Access Channel"

- *Authors:* Xiao, J.-J. and Luo, Z.-Q.

- IEEE Transactions on Information Theory, Vol. 53, No. 9, pp. 3255-3264, September 2007.

(6) "Linear Coherent Decentralized Estimation"

- *Authors:* Xiao, J.-J., Cui, S., Luo, Z.-Q., and Goldsmith, A.J.
- IEEE Transactions on Signal Processing, Vol. 56, No. 2, pp. 757-770, February 2008.

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